DESIGN, CONSTRUCTION AND TEST

OF A

STEAM AIR-EJECTOR

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DESIGN, CONSTRUCTION AND TEST OF A STEAM AIR EJECTOR

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ILLUSTRATIONS AND LOG SHEETS

STEAM AIR-**EJECTOR**

INTRODUCTION

The study of the steam air-ejector opens
up a field which is intensely interesting. This
thesis covers, of necessity, only a small area
in the search to find something useful to the
engineering profession. It is with this thought
and hope in mind that we have launched out on
new waters of experimentation. It is hoped that
our work will not be set aside, but will be
carried on by the future students at the Armour
Institute of Technology.

The authors desire to express their gratitude
and indebtedness to their teacher, Professor
George F. Gebhardt, whose deep interest and co-
operation have made this report possible.

The subject has herein been presented in
two parts:- the first, the general principles
and important factors which enter in, and second,
an application of these to a concrete example.
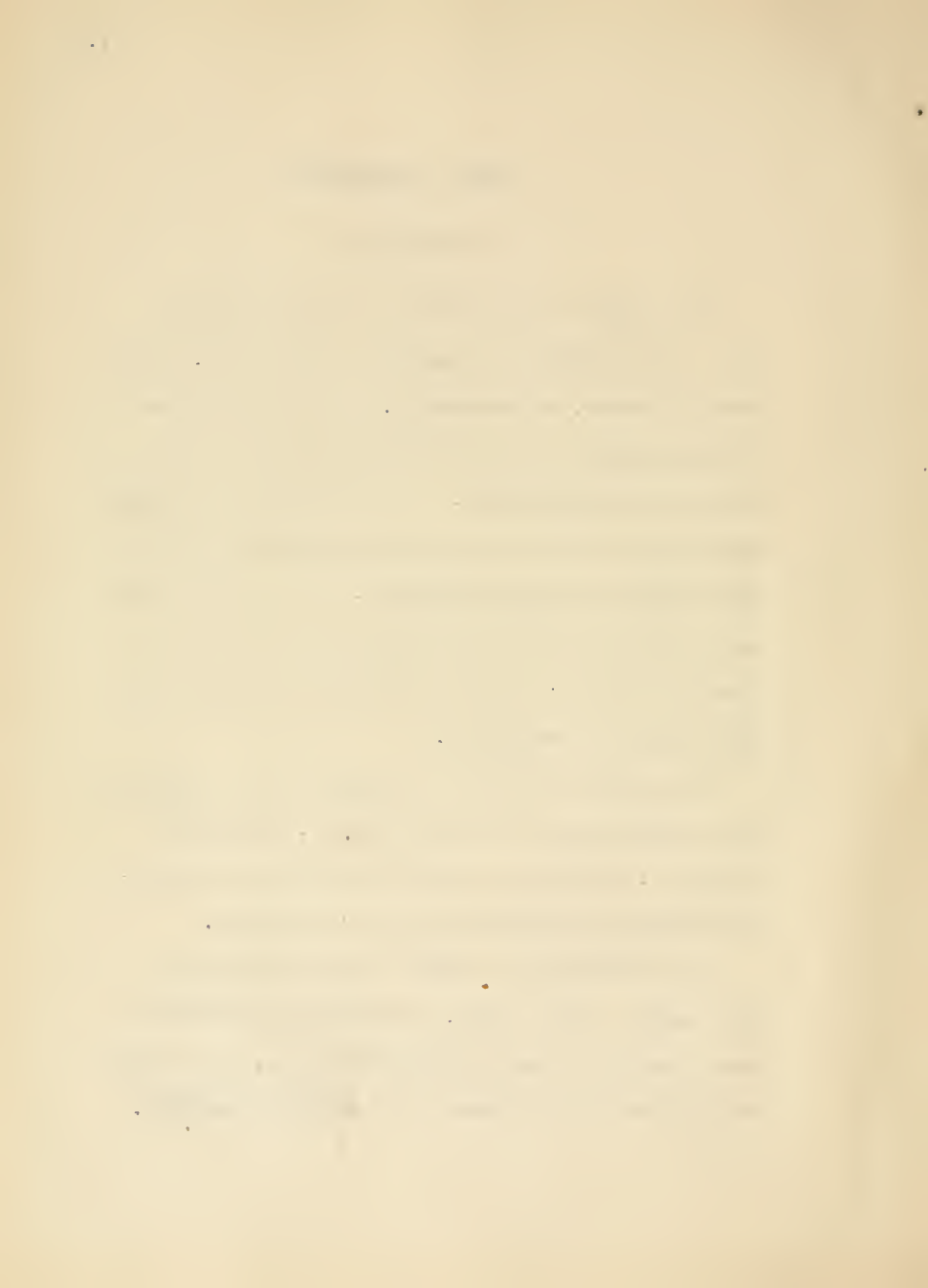
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A survey of what work and results of experimentation has already been accomplished is given in part #1. The design of some of the machines, which are already on the market, is also given.

The calculations, design, construction, and testing of a particular apparatus for the removing of air from condensers, when a high degree of vacuum, is desired are given in part #2.

In this day of high efficiency, limited floor space, low maintenance cost, and dependability of machines, the steam turbine, as a prime mover, has, no doubt, come to stay. With the turbine came the demand for condensers of a large capacity and capable of maintaining a high degree of vacuum. It depended chiefly upon the air pump to maintain this vacuum. Hence an air pump of minimum space requirements, highest efficiency, and lowest maintenance cost, is a

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machine which is most desirable. Much has
yet to be done before such a machine will be
brought forth.

Steam air-ejectors, for removing air have
been known and used as early as 1868, but
never with the thought of producing a high vac-
uum, commercially. This was due to the fact
that the demand for a high vacuum was created
only when the steam turbine became one of the
standard prime movers for power plants.

The knowledge of the properties of steam
at this time was based mainly on the classic
investigation of Regnault.

Steam air-ejectors operate on the dry air
principle. It is desirable that they be highly
developed because of their mechanical simplicity,
ruggedness, absence of moving parts, (and hence
the absence of lubrication), and durability,
(because of their design and construction).

The Radojet Air Pump, which is built by the

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C. H. Wheeler Manufacturing Company, is
perhaps one of the most advanced air-ejectors
that is on the market at the present time.

The Radojet consists of two steam ejectors
working in series; the upper ejector being
called the first stage, and the lower one, the
second stage.

Referring to Fig. #1, the live steam is
delivered at 'L', and from there it passes
through a strainer #1, through pipe #2, auxil-
iary steam valve #3, strainer #4, and into the
expansion nozzles #5. It then crosses the suc-
tion chamber #6 of the first stage ejector.
This chamber is in direct communication with
the condenser through the opening #S.

The steam expands in the nozzles, leaving
them with a very high velocity. While passing
the suction chamber #6, it entrains the air and
vapors, which are to be compressed up to the
pressure of the atmosphere.

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The mixture then passes into the diffuser
#7. Here it is discharged at a higher absolute
pressure than that of the air entering at 'S'.
It then enters into a double passage #8, which
communicates with the suction chambers #9 of
the second stage. These two suction chambers
are annular, giving the commingled gases a
large entrainment surface.

Steam is simultaneously delivered through
the strainer #1 into the passage #10. This
communicates with annular expansion nozzle,
which is formed between the two circular discs
#11 and #12. Disc #12 may be adjusted by means
of screw #13, to vary the cross section of the
nozzle passage. Hence the expansion ratio of
the steam is changed.

The steam, delivered radially by the annular
nozzle #11 and #12, expands leaving it as a jet
of high velocity in the form of a disc. In pass-
ing across the suction chamber #9, it entrains
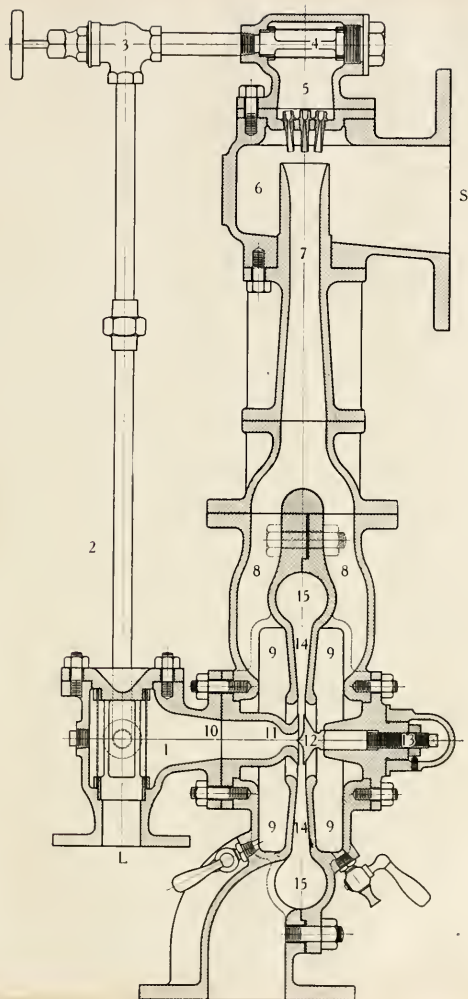
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the air and steam coming from the first stage.
The commingled air and steam passes into the
annular diffuse #14, and the mixture is then
compressed up to atmospheric pressure. The
mixture is then discharged into casing #15,
which has a discharge opening #D.

The steam nozzles and the diffuser are de-
signed scientifically to give the highest over-
all efficiency. The nozzles of the first stage
are bronze and those of the second stage are
of a bronze steel. The diffusers of bronze and
accurately machined. In the smaller sizes, the
diffusers are a part of the casting, while in
the large sizes the diffusers are secured to a
cast iron casing by bolts. These form a ground
metal to metal, joint with the casing.

The strainers ahead of the nozzles are
easily removed for cleaning.

Figure #2 shows a method of discharging the
mixture into a tank supplied with fresh water

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for the boiler. The steam contained in the
mixture is condensed and the heat transmitted
to the boiler feed water, raising its tem-
perature. The air frees itself from the rais-
ing water and escapes through a vent to the
atmosphere.

Another design of an ejector air-pump,
or steam air-ejector, is being put on the
market. After many months of arduous research
work, during which time many set-backs and
innumerable difficulties were overcome, the
inventor, Maurce Leblanc, evolved a fairly high
class pump.

Figures #5 and #6 show the general arrange-
ment of this apparatus. The pump is arranged
to work in two stages, steam being admitted
to the second stage by the valve 'C'. Imme-
diately 'C' is opened, steam fills the annular
space behind the nozzle plate and finds its
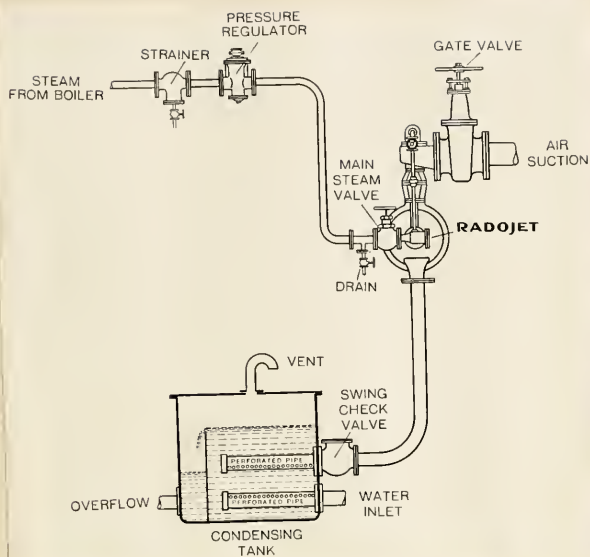way into the throats of the group of nozzles,

FIG. 2

STEAM AIR-EJECTOR

'Y', which are attached to this plate. The
method of supplying the first stage with steam
is readily seen from the picture. The pump is
connected to the condenser at the branch 'D',
which is the air inlet. At the entrance to
each of the steam spaces back of the nozzles,
fine wire gauze strainers are fitted to prevent
any foreign matter, which may have primed over
from the boiler, from entering the nozzles.
A stoppage of one or two of the nozzles might
mean a loss of the vacuum.

The nozzles are securely locked to the
nozzle plates. The mixture of air and steam
is discharged at the mouth of the cone 'Y',
and lead away to a feed water heater of the
open type. In this manner a part of the heat
of the steam is reclaimed.

To start the pump, the valve 'C' is opened
and a certain degree of vacuum is attained in
the condenser. When the needle of the vacuum

Steam to 1st Stage Nozzles

2nd Stage Nozzles

STEA INLE C

STEAM AND AIR DISCHARGE

1st Stage Nozzle

AIR INLET D

X

Y

FIG. 5
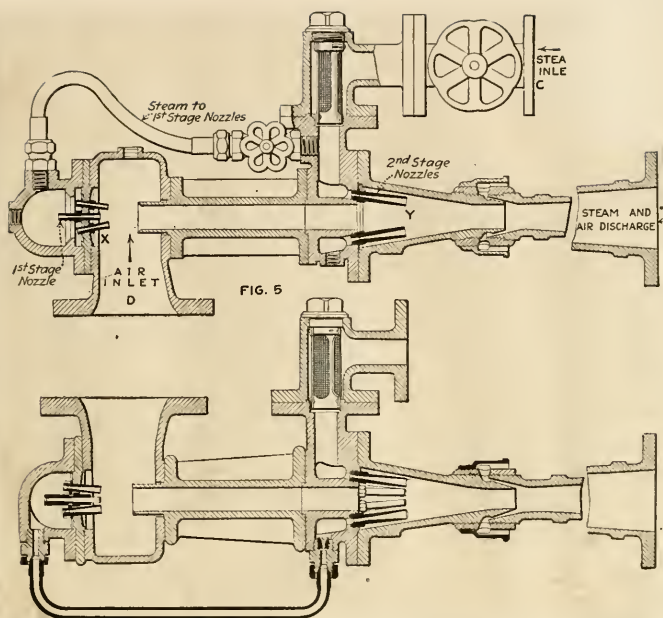
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gauge becomes stationary, the inlet steam
valve for the second stage is opened and the
maximum degree of vacuum is obtained in a short
time.

A very important factor in this type of
pump is the absence of moving parts.

This Leblanc air pump, although apparently
having a rather high steam consumption is really
very efficient and economical. This machine gives
back about ninety-five percent of the original
heat of the steam.

Figure #7 shows the form which the steam
jet is though to take, upon expansion into a
high vacuum. The steam, issuing from the mouth,
expands and contracts alternately. It ultimate-
ly assumes a constant cross sectional area.
Leblanc found that a number of these nozzles
grouped together gave far better results than
a single nozzle with a throat area equal to the
aggregate area of the smaller nozzles. The

FIG 7
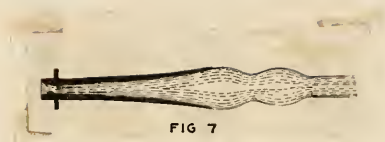
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reason for this is that the alternate increasing and decreasing of the cross sectional area of the jets is minimized by the contact of one steam jet with next, when groups of nozzles are used. This helps considerably to increase the surface available for entrainment of the air.

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DESIGN OF PRIMARY NOZZLE (theoretical)

The design of the first stage nozzle resolves itself into the following problem:-

Assume a diameter of throat opening and back pressure at end of nozzle. Having given the available steam pressure, follow through the calculations and design of a nozzle. Compare these calculated dimensions with the required ones for such a nozzle.

Hence, given 100# gauge, (or 115# abs.), initial pressure, .94# abs. back pressure and 1/4" diameter throat. Initial steam assumed as dry.

$$Dia. = 1/4"$$

$$B_2 = .58 \text{ x } 115\# = 66.7\# \text{ abs. press.}$$
in the throat.

$$P_1 = 100\# + 15\# = 115\# \text{ abs.}$$

$$P_7 = 28\# \text{ vacuum} = 1.92 \text{ x } .49 = .94\#$$
abs.

Area of 1/4" throat = .4915 sq. in.

= .000341 sq. ft.

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$V = 224 \sqrt{H_1 - H_2}$

where, H_1 = heat at 115# = 1188.7 B.T.U.

" H_2 = heat at 66.7# = 1145 B.T.U.

Assuming adiabatic expansion,

$V_2 = 224 \sqrt{1188.7 - 1145}$ = 1480 ft./sec.

From Moller diagram,

V_1 = 3890 ft./sec. velocity.

X_2 = .964

'S' at 66.7# = 6.48 (from steam tables)

.964 x 6.48 = 6.25 cu. ft./#

also

$V_8 = 224 \sqrt{H_1 - H_8}$ (where H_1 at 115# &
" H_8 at .94#)

= 224 $\sqrt{1188.7 - 885}$

= 3890 ft./sec. (check)

E_1 = 778 (1188.7 - 1145)

= 34400 ft./# of energy in the steam.

A = WS/V

where $_1A$ = area in sq. ft. of nozzle opening.

" W = wt. of steam,

" S = specific volume

STEAM AIR-EJECTOR

where V = vel. ft./sec.

$$.000341 = \frac{W \times 6.49}{1480}$$

= .0778# steam/sec.

or .0778 x 3600 = 284# steam/hr.

This is theoretically the amount of steam which will pass through the nozzle per sec. by expanding from 115# abs. boiler pressure, to 66.7# pressure in the throat.

The areas, or diameters, of the different sections at the respective pressures of 66.7#; 40#; 14.7#; 8#; 4#; 2#; & .94# (discharge press.) were obtained in the following manner; i.e. at 8# pressure.

$$A = \frac{.0778 \text{ (lbs. steam/sec.) x S(specific vol. @ 8\#)}}{3060 \text{ (vel. in ft./sec.)}}$$

= .475" dia.

= .00121 sq. ft. area.

This method gives a diameter of 1.156" at .94# back pressure. There are losses which enter in and change the quality, volume, and velocity
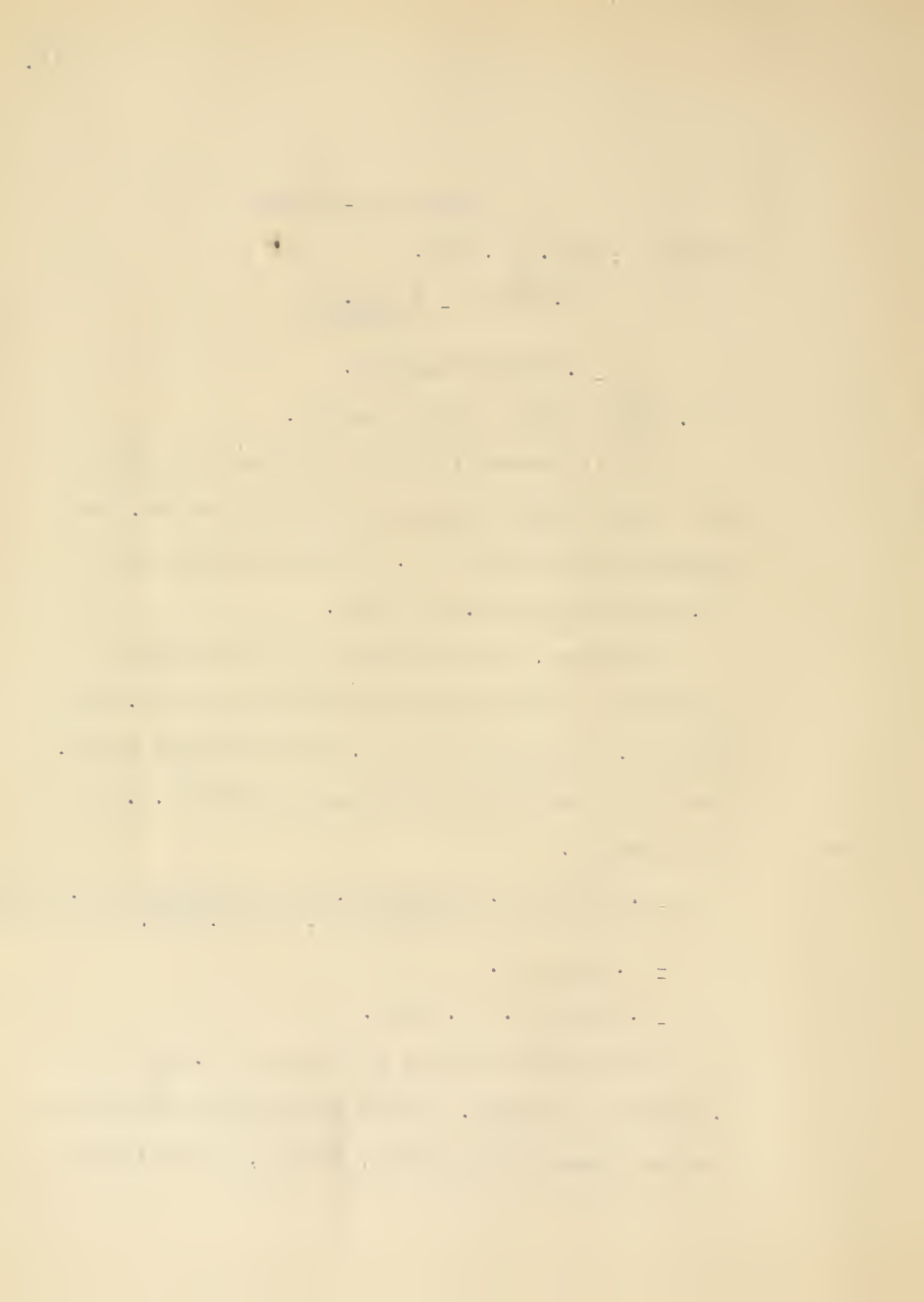
STEAM AIR-EJECTOR

of the steam. It is necessary to allow for
these in the working nozzle. The calculations
for this nozzle will be given later.

The total heat, quality and velocity used
in these calculations were obtained from the
Moller diagram, (the velocity being checked by
calculation).

$$F = \frac{W \times V}{g}$$

where F = no. foot-lbs.

" W = wt. of steam,

" V = vel. in ft./sec.

" g = 32.2 ft./sec./sec.

$$F \text{ (at } 4\#) = \frac{1 \times 3370}{32.2}$$

$$= 104.6 \text{ ft. -lbs.}$$

also

$$d = \sqrt{\frac{144 \times 4}{3.1416}} \times A, \text{ (where A = area in sq.}$$
$$\text{ft. of cross section.)}$$

$$= 13.65 \sqrt{.00705}$$

$$= 1.15" \text{ dia. at discharge.}$$

P # PRESS.	H TOTAL-H'T.
P_1 115 #	1188.7
P_2 66.7 #	1145
P_3 40 #	1108
P_4 14.7 #	1039
P_5 8 #	1002
P_6 4 #	961
P_7 2 #	923
P_8 .94 #	.886

THEORETICAL NOZZLE.

P PRESS.	H TOTAL-H'T.	x QUALITY	u SP. VOL.	$S=xu$ ACT'L VOL.	V VEL.FT/SEC	E FT-LB	A SQ. FT	d DIA-IN.	F POUNDS
P_1 115#	1188.7	1.00	3.88	3.88	0	0	∞	∞	0
P_2 66.7#	1145	.964	6.49	6.25	1480	34,400	.000341	.25	46.0
P_3 40#	1108	.935	10.49	9.8	2010	62,800	.000406	.275	62.4
P_4 14.7#	1039	.886	26.8	23.75	2740	115,900	.00076	.377	85.1
P_5 8#	1002	.862	47.27	41.5	3060	145,200	.00121	.475	95.0
P_6 4#	961	.837	90.5	75.7	3370	177,000	.00209	.625	104.6
P_7 2#	923	.813	173.5	141	3643	213,000	.00370	.832	113.2
P_8 .94#	.886	.791	350.8	274	3890	234,500	.00716	1.156	12.07

VAK. 19-25-18.

STEAM AIR-EJECTOR
DESIGN OF WORKING NOZZLE

The design of this nozzle takes into
consideration the increasing quality of the
steam, due to the friction in the nozzle.

The length of the nozzle will not change
from the theoretical.

This nozzle, like the theoretical one,
presents the following problem:

$d_1 = 1/4" = .4915$ sq. in. $= .000341$ sq.ft.

$P_1 = 100\#$ ga. $= 115\#$ abs.

$P_2 = .58 \times 115\# = 66.7\#$ abs. pressure in
throat.

$P_8 = 28"$ vacuum $= 1.92 \times .49 = .94\#$ abs.
pressure.

The energy loss is converted into heat and
hence tends to dry out the steam. Assuming a
10% energy loss and calling this loss $= 'y'$

$$V = 224 \sqrt{(1 - y)(H_1 - H_2)}$$

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where H_1 = heat at 115# = 1188.7 B. T. U.

" H_2 = heat at 66.7# = 1145 B.T.U.

$$V = 224 \sqrt{(1 - 0.1)(1188.7 - 1145)}$$

$$= 224 \sqrt{.9 \times 43.7}$$

= 1405 ft/sec. vel. of steam in the

entrance.

QUALITY OF THE STEAM AT VARIOUS POINTS.

X_1 = real quality,

X_8 = theoretical quality

r_8 = latent heat of vaporization

$X_1 = X_8 - I_8 = X_8 - y(H_1 - H_8)$

Increase in quality;

$$= \frac{.1 \times (1188.7 - 886)}{1035.6}$$

$$= .0294$$

Real quality = .0294 - X

$$= .0294 - .791$$

= .810 for the discharge quality.

FOOT-LBS. OF ENERGY IN THE STEAM.

$$E = 778 \times \sqrt{(1 - y)(H_1 - H_2)}$$

$$= 778 \times \sqrt{(1 - 0.1)(1188.7 - 1145)}$$

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$\doteq$ 31,000 ft. lbs. of energy at throat

AREA IN SQ. FT. OF NOZZLE

$$A_8 = \frac{WX_1 \times U}{V}$$

where A $=$ area in sq. ft.

"   W $=$ wt. of steam passing through nozzle.

" $X_8 =$ quality of steam (real).

" $U_8 =$ specific volume of steam at .94#

$$A_8 = \frac{.0778 \times 81 \times 350.8}{3760}$$

$$= .00588 \text{ sq. ft.}$$

but, $A_1 = 1/4 \times 3.1416 \times d^2 = .758d^2$

$$d = \sqrt{\frac{.00588}{.785}}$$

$$= .0865 \text{ ft. dia.}$$

$$= 1.038"; \text{ say 1" at end of nozzle.}$$

FOOT-LBS. OF ENERGY

$$F = \frac{W \, V}{g}$$

$$= \frac{.0778 \times 3760}{32.2}$$

$$= 116.7 \text{ ft. lbs.}$$

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LENGTH OF NOZZLE.

'L' $= \sqrt{15 \times a}$ where 'a' $=$ dia. at throat.

$= \sqrt{15 \times .25"}$

$=$ 1 & 15/16" length from throat.

P PRESS (ABS)	$V.$ VEL. FT/SEC
P_2 66.7#	1405
P_3 40#	1908
P_4 14.7#	2590
P_5 8#	2900
P_6 4#	3230
P_7 2#	3445
P_8 .94#	3760

ACTUAL NOZZLE.

P PRESS (ABS)	V. VEL. FT/SEC	E FT. LBS.	x QUALITY	A AREA, SQ.FT.	d DIA. INCHES	F POUNDS.
P_2 66.7#	1405	31,000	.9688	.000341	.250	43.6
P_3 40#	1908	56,500	.9416	000404	.275	59.2
P_4 147#	2590	104,200	.9014	.000719	.363	80.5
P_5 8#	2900	130,600	.8809	.001027	.515	90.1
P_6 4#	3230	159,300	.8597	.001863	.584	100.3
P_7 2#	34.45	191,700	.8390	.003275	.776	106.9
P_8 9.4#	37.60	210,600	.8100	.00588	1.038	116.7

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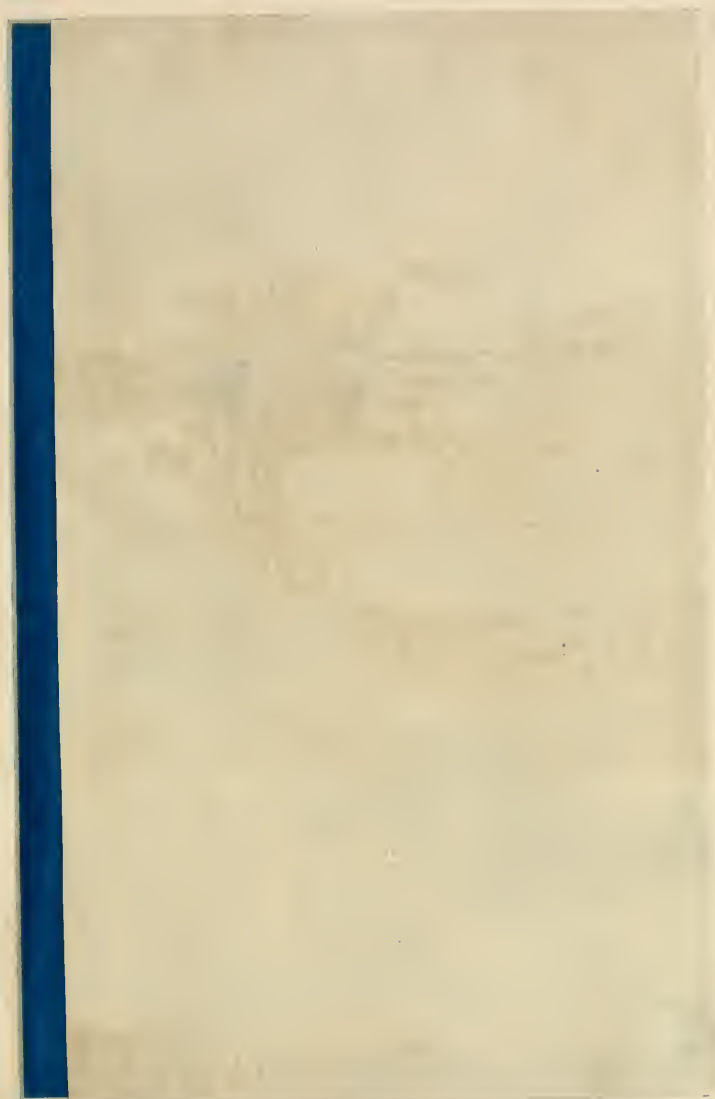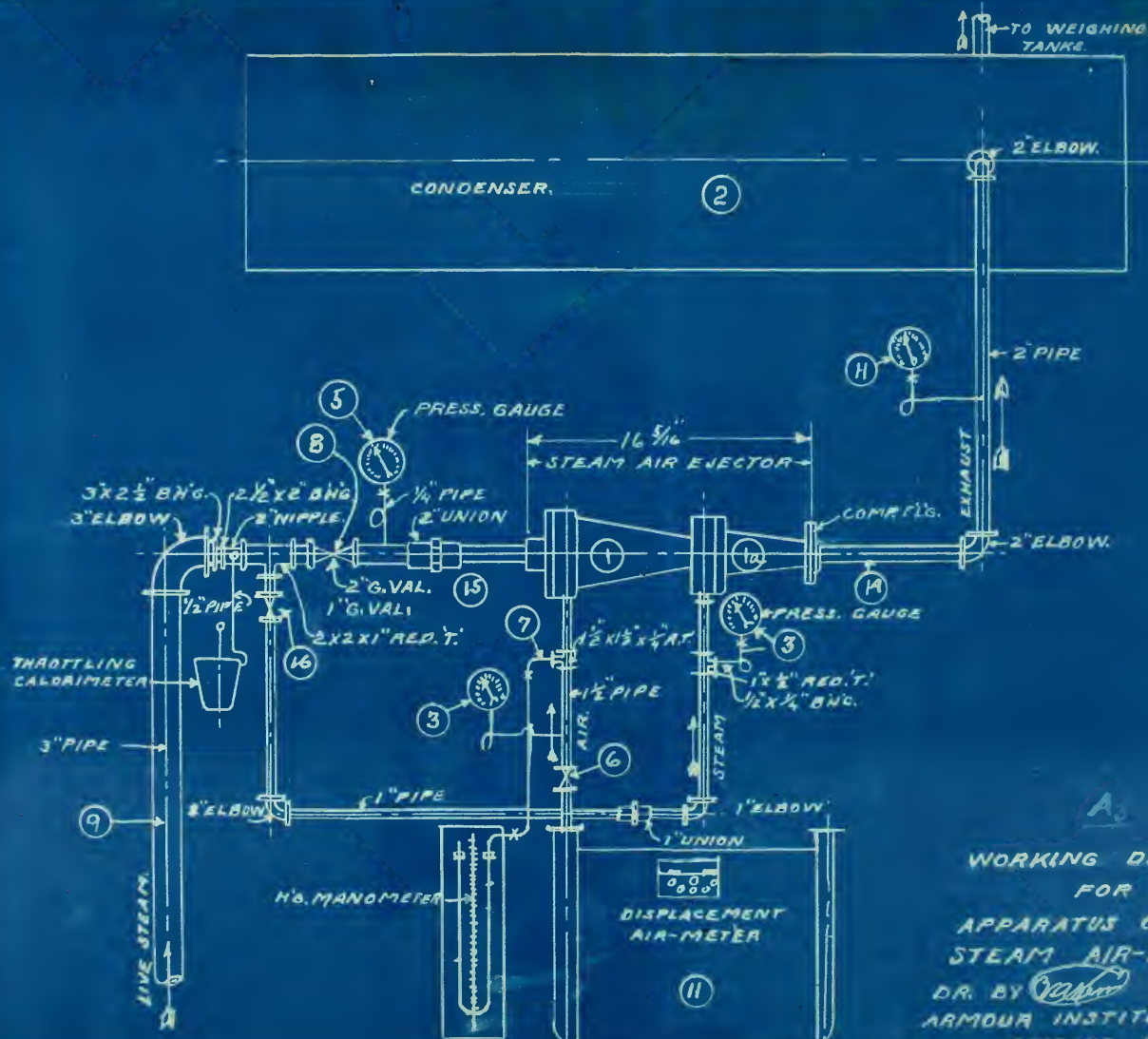
WORKING DRAWING
FOR
APPARATUS OF
STEAM AIR-EJECTOR.
DR. BY *[signature]* FEB. 1918
ARMOUR INSTITUTE OF TECH.
CHICAGO, ILL.

STEAM AIR-EJECTOR
METHOD OF CONSTRUCTION

The upper combining shell was made of cast
iron. The surface of the top joint was turned
corrugated to prevent the packing from blowing
out. A light cut was taken from the inside of
this piece. This lessened the friction of the
gases, which are traveling at a high velocity.

The surfaces of the lower joint were turn-
ed smooth in order that the joint might not
leak when a metal to metal contact was desirable.
The inside of the lower nozzle, forming this
piece, was turned central with the outer edge
of thesteam passage. This outer edge was made
with a sliding fit, over the shoulder of the
lower combining shell. It was in this manner
that the nozzle was centered.

The lower combining shell was finished with
a light cut on the inside to reduce friction
on the high velocity gases. The outer edge of

STEAM AIR-EJECTOR

the lower nozzle, (on the inner side of the
upper combining shell), was finished smooth
to exact size.

The upper and lower combining shells were
fitted together, by means of the centering
shoulder. When the two smooth surfaces came
in contact, it left an opening of between 1/64
and 1/100 of an inch all around the circumference
of the secondary nozzle. By inserting a pack-
ing of a known thickness in the joint, a known
width of opening of the nozzle could be obtain-
ed. The nozzle was made of brass and filled on
the inside to reduce the friction, which causes
a loss of energy in the steam. Threads were
cut, on the opposite end from the discharge,
leading up to the shoulder, so that the nozzle
could be screwed tight up against the top plate.
By this means washers could be inserted between
the shoulder and the top plate, if it was desir-
able to change the position of the nozzle.

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The calculations show that the nozzle should not be as long as the blueprint calls for. The authors thought that with the extra length of nozzle, a 'rolling action' could be produced on the sides of the jet that would cause a greater entrainment of air. The nozzle is so designed that it could be cut off to the theoretical length, if it is shown through the subsequent tests that the extra length of nozzle is not desirable.

STEAM AIR-EJECTOR
TESTING AND OPERATION

The ejector was set up for testing in the
north-east end of the engine room of the Armour
Institute of Technology. A plan of the apparatus
and its construction is given in the illustration
#A_2. In this illustration all the fittings and
apparatus are shown to be swung up into the plane
of the paper. In illustrations #A_1 and #A_3 the
actual apparatus is shown as it was when it was
being tested. The live steam pipe, #9 in #A_3,
feeds direct from the boiler to the ejector. The
steam coming so direct from the boiler, it was
permissable to assume that it had a quality of
100%, in the calculations of the tests that
follow. This was also assumed in the calculations
of the nozzle.

The live dry steam, coming through pipe #9,
goes through valve #8 and enters the primary
nozzle at #1. It then goes through the ejector
and out the exhaust #14. This gives the opera-

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tion of the first nozzle alone, assuming that valve #16 is closed.

To operate the secondary nozzle alone, valve #8 was closed and the live steam goes through valve #16 and into the secondary nozzle at $#1_a$. The commingled air and steam then pass out the exhaust #14. To operate both nozzles, valve #8 and #16 are both opened and the steam passing through them comes together again in the lower combining shell, $#1_a$, and hence to the exhaust. The air that was sucked in came through the pipe #17 and valve #6. This pipe connected on to a displacement air meter #11, which was capable of handling about 125 cu. ft. of air per minute. This was sufficient for the ejector.

The exhaust leads to a counter-current condenser, #2, that had been opened to the atmosphere. This virtually makes it an open type of condenser. This was necessary in order that
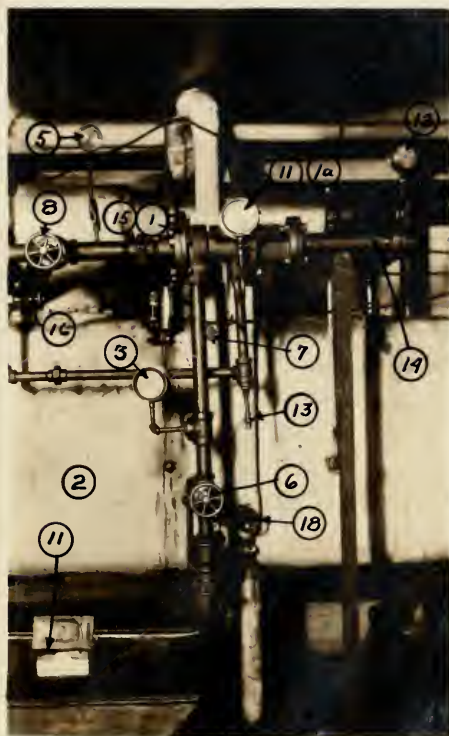
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the air, which had been entrained in the
steam, could have an outlet.

A reciprocating pump was situated direct-
ly under the condenser. This machine pumped
the condensed steam, and a certain amount of
air, into either one of two weighing tanks.
These tanks were situated about 10 feet back
of the condenser and in the south end of the
wash and locker room. The live steam, to ac-
tuate the pump, was admitted through the valve
#18.

In starting to run a test on the ejector
as a whole, the steam was first admitted slow-
ly to the line #9, by means of a gate valve and
a separator (not shown), so as not to cause
'Water-hammer'. The valve #16 was then cracked
open and the drip of valve #19 was allowed to
drain off through valve #16, down through the
drip-cock #13, and into a pail on the floor.
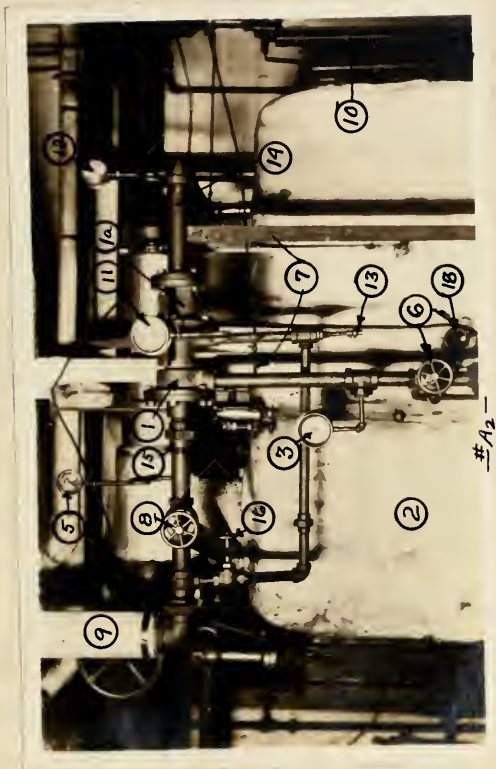The cooling water from the city mains was then

-#A₁-

#A₂ —

STEAM AIR-EJECTOR

started through the condenser. This was forced
through by city pressure alone, no pump being
used for this circulation. The condenser pump
was then started by admitting steam through
the valve #18. This pump pumped the condensed
steam into the above mentioned tanks which
rested on platform scales and were capable of
holding about 1800 to 2000 lbs. of water.

When the drip was drained off, the valve
#16 was opened full. This let steam to the
secondary nozzle. It was thought best to let
the steam through the secondary nozzle, first,
in order to build up a vacuum in the upper
combining shell. The valve #8 was now opened
and the steam was admitted to the primary, or
first stage nozzle, after having created as
high a degree of vacuum as possible. The valve
#6, from the air meter, was now cracked open.
This was done because the drip from the steam
pipe had collected in the air pipe above the

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valve #6. In this way the collected water was gradually taken into the ejector and hence into the condenser. When the ejector was well heated up, the air valve, #6, was opened full.

The boiler pressure was read on gauges #4 and #5. The degree of vacuum was read on gauge #3, and also on the manometer, #10. This manometer lead to the suction pipe by means of the tube, #7. The amount of air drawn in was read from the meter at #11. The amount of condensed steam was weighed by means of the tanks on the platform scales in the locker-room.

In starting the first test, the secondary was turned on first. Instead of creating the desired vacuum, it caused a back-pressure. The authors thought that the reason for this was that this secondary nozzle had too wide an opening. Because of this, the steam was not direct-ed down, but rather in a course that was diagonal
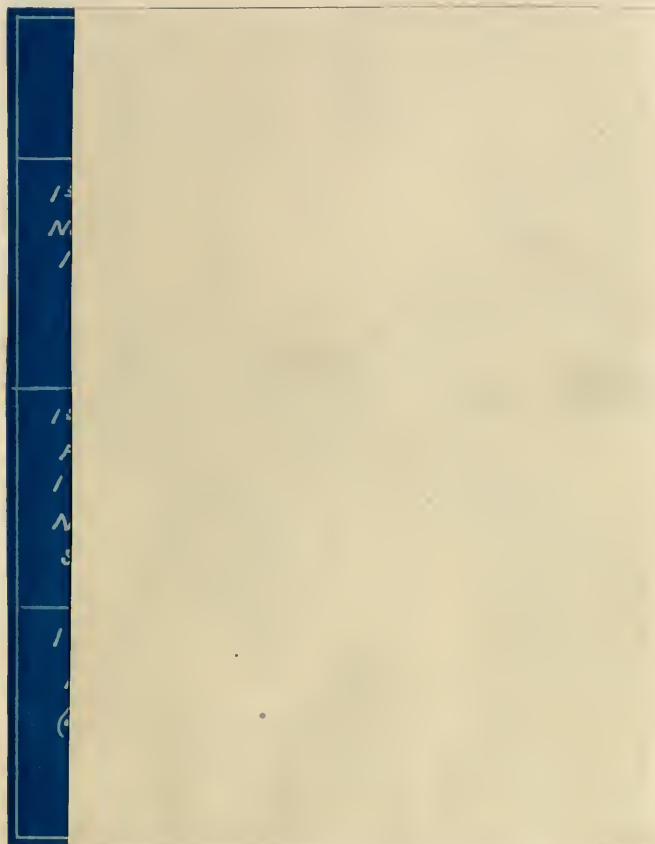
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across the lower combining shell. By follow-
ing this course, the steam from one side of
the nozzle met the steam coming from the other
side at a comparatively wide angle. As a re-
sult of this there was a combined splash and
'rolling-back' action produced, causing the
steam to build up pressure in the upper combin-
ing shell.

The first nozzle was turned on at this
time with the secondary nozzle and a vacuum of
about 1" was created. When the secondary nozzle
was turned off and the 1st left on running, with
wide open valve and under 93# pressure, a vacuum
of 2.75" Hg. was created. When the air was shut
off fully and maintained about 1" Hg. vacuum
and pulled about .47# of air per # of steam.
(see log blue print for test #1).

The above results were of little value, hence
more elaborate tests and data were unnecessary.

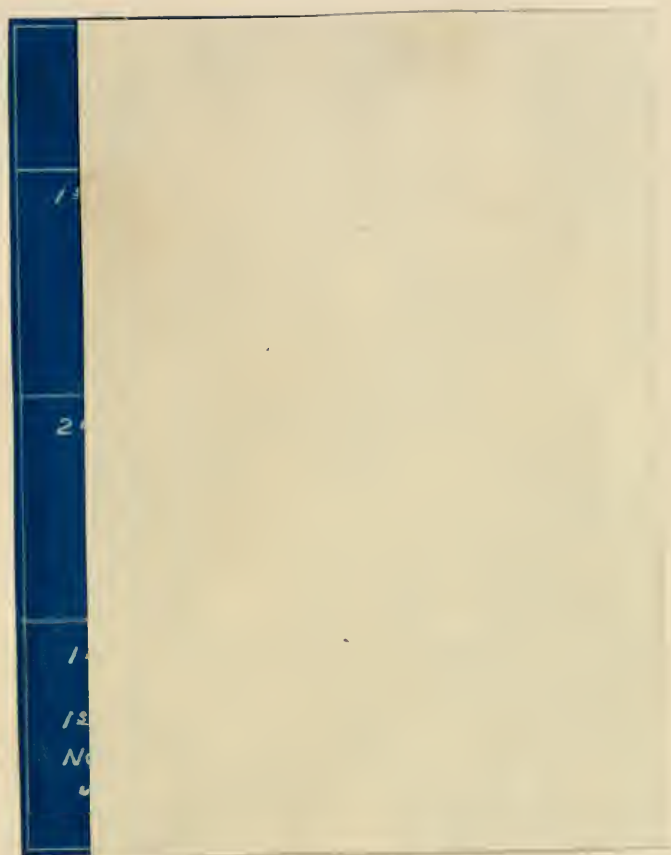The gasket from the lower joint was taken

CONDITIONS OF OPERATION OF AIR-EJECTOR	STEAM PRESSURE GAGE	FREE AIR CU. FT. PER HOUR	STEAM LBS. PER HOUR	FREE AIR CU. FT. PER LB. OF STEAM	LBS. AIR PER LB. STEAM	VACUUM IN. OF HG.	
						AIR VALVE OPEN	AIR VALVE CLOSED
1ST STEAM JET OPEN NOZZLE LONG 1" DIA. AT OUTLET. (TEST #5)	92	2100	315	6.66	.538	.5	1
1ST & 2ND STEAM JETS FULL OPEN. 1ST NOZZLE LONG NO GASKET AT STUDED JOINT (TEST #4)	103	498	321	1.55	.125	0	3/4
1ST STEAM JET OPEN 1½" PIPE INSERTED (SEE B PRINT NO.) (TEST #6)	103	3810	474	8.03	.65	2½"	5

CONDITIONS OF OPERATION OF AIR-EJECTOR	STEAM PRESSURE GAGE.	FREE AIR CU. FT. PER HOUR	STEAM LBS. PER HOUR	FREE AIR CU. FT. PER LB. OF STEAM	LBS AIR PER LB. STEAM	VACUUM IN. OF HG.	
						AIR VALVE OPEN	AIR VALVE CLOSED
1ST STEAM JET OPEN ¼" NOZZLE — LONG (SEE B.PRINT NO.) (TEST #1)	93	2350	404	5.81	.47	1	2.75
2ND STEAM JET OPEN NO GASKET AT STUDED JOINT— NOZZLE ABOUT ⅛" OPEN (TEST #2)	105	2090	190	11	.88	1	2.75
1ST + 2ND STEAM JETS OPEN. (FULL) 1ST NOZZLE. LONG NO GASKET AT STUDED JOINT. (TEST #3)	93	690	471	1.46	.118	0	1

STEAM AIR-EJECTOR

out in order to lessen the opening in the
secondary nozzle. This coincided with the
above stated ideas that the back-pressure was
caused by the steam from the secondary nozzle
not having had the right direction in its ex-
pansion. The latter was caused by too great
an opening in the secondary nozzle.

In this next test no run was taken on the
primary nozzle alone as the conditions under
which it operated in the first test, were not
altered.

The secondary nozzle was made longer by
putting the upper combining shell in a lathe
and cutting down the upper face of the lower
joint and also the outside of the inner edge of
the nozzle. Hence it was calculated to give a
little less than 1/8" opening, as any less than
this would result in wire-drawing. This was
done in view of the fact that the steam should
be given a better direction, and hence a better

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expansion. The latter was to be obtained by
having the nozzle longer and of a smaller
angle with a geometrical axis of the ejector.

By running the secondary nozzle alone
under 105# of steam, it gave a vacuum of 2.75"
Hg. with the air entirely shut off. It main-
tained a vacuum of 1" Hg. with the air valve
full open. The secondary nozzle, operating
under these conditions, gave better efficiency
than the primary nozzle did running alone. The
secondary was now a little less than 1/8" open;

This run, by giving better efficiency,
which was almost double the other, proved that
the authors were working along the right line
for the improvement of the ejector.

In the test #3, both jets were full open
with a 93# steam pressure. The results of this
run show a slight improvement, but it still shows
that the two stream lines from the nozzles were
causing an eddying, by coming together at too

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great an angle. The cause of this was un-
doubtedly a rolling-back action that destroy-
ed any vacuum which was created by the primary
nozzle.

Before run #5 was made, the apparatus was
taken down again and the primary nozzle cut off
to the calculated length. From the results of
run #5, it shows a better efficiency than before,
but a smaller capacity. This shows that the
theory of the 'rolling-up' action of the steam,
due to the extra length of nozzle, did make a
greater entrainment of air, but it was done so
at the expense of efficiency.

With the results of these tests at hand,
the authors thought that the entrainment space
was entirely too large to have these stream
lines not conflict with each other. This space
begins at a point a little below the primary
nozzle and extends to the point at which the
steam from the secondary nozzle entrains the

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comingled air and steam coming from the primary
nozzle. The velocity with which the gases go
through the combining chamber, and also the
manner in which they go down the middle of this
space, necessarily leaves a dead space at the
sides. With such a space present, the vacuum
which had at first been created by the steam,
as it first left the nozzle, was destroyed by
air and steam backing up into this space. The
action is similar to the action which would take
place in a hydraulic ram if the cylinder was
entirely too large for the piston. That is,like
leaving a space between the piston and the walls
of the cylinder and then trying to build up a
pressure.

To overcome this, it was thought that an
additional part could be put into the machine
so that the part, which was introduced, would
be entirely filled by a stream of high velocity
gases. Hence the tendency for a dead space to

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form along the sides would be eliminated and
the ejector could maintain a high degree of
vacuum. If this fast moving stream could be
conducted so that it would not have to pass
through the trubulent, or back-eddying part,
of the lower combining shell, it would help
to direct the stream lines in this part of the
ejector. It is here that the stream from the
secondary nozzle comes together and enters
this stream below this point. In this way much
of the energy of the streams would not be dis-
sipated by coming together at a comparatively
large angle. Although this might cut down the
capacity a little, yet, this is not as important
to maintain as a high degree of vacuum.

In the assembly blueprint, #2, is shown the
method by which this problem was attacked. In
this is shown a cast iron collar which fits up
against a shoulder at the base of the air pass-
age. This shoulder was made by running an extra

STEAM AIR-EJECTOR

cut down the indise of the upper combining

shell, and stopping it at this point. This

collar fits with a tight fit in the shell and

has sufficient bearing length so that it will

always remain in the same position. Inside of

the collar it was threaded and a 1 and 1/2"

pipe was screwed in until the end of the pipe

came flush with the top side of the collar.

The upper edge of the pipe and collar was round-

ed off to give a good entrance for the comming-

led air and steam. The pipe was long enough to

extend below the back-eddying space in the lower

combining shell. It discharged into the center

of the high velocity stream of steam coming from

the secondary nozzle. In this manner a large

part of the dead space, which was a drag on the

machine, was placed in a position so that it

would not be detrimental to the vacuum created

in the ejector.

The collar, holding the pipe, was held in

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place by means of cap-screws inserted from the outside, as shown in the blueprint. The pipe depended solely upon the collar for its support in a central position.

When the steam was turned on the ejector, containing this part, it was found that the secondary nozzle opposed the first, and caused a back pressure. Hence no run could be made with the secondary nozzle.

A run was made, however, on the first nozzle alone. As seen from the log blueprint it gave nearly twice the capacity that any previous run did and also with about an average efficiency. In this run a vacuum of 5" Hg., with the air shut off, and 2 and 1/2" Hg., with the air full on, was maintained steadily through the run.

This run shows that the problem was being attacked along the right line, so far as the first stage was concerned.

The reason for the secondary nozzle's creat-

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ing a back pressure was that the steam coming
out of this nozzle came at such a comparative-
ly wide angle with the central axis of the
ejector. It therefore encountered the pipe,
which interfered with the direction of the
stream line and caused an eddying and a disturb-
ance. This caused a back pressure and a loss
of efficiency.

The authors were lead to the following
new design of steam air-ejector, after a study
of the results and data obtained from these
tests. It is believed that the new design will
rectify many troubles, which were prevalent
in the earlier machine, and will give much better
results.

It is hoped that the following design will
be taken up by future students and the machine
built with improvements made upon it if possible.
Although the present machine is a long way from
perfection, yet that degree is obtained only by

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making these necessary steps leading to it.

STEAM AIR-EJECTOR

THE PROPOSED NEW DESIGN OF STEAM AIR-EJECTOR

In this design the authors still adhere to
the same principles of the old ejector. To utilize
this principle to a better advantage, the design
was changed. With the exception of the secondary
nozzle, the new design consists mainly of different
proportioning of the combining chambers.

Referring to the blueprint of the new design,
#4, is the live steam entrance to the primary
nozzle, #5. The steam passes through this nozzle
entraining the air which is coming through the air
inlet, #6. The commingled air and steam pass into
the combining chamber, #7. Going from this chamber,
the gases pass around the part #8, and are again
entrained by the jet #9, in the lower combining
chamber. They then pass out through the exhaust
#11, into the condenser.

In this design we see the shape of the upper
combining shell was reconstructed on the final
drawing. The steam and air enter, in this case,

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through the rather narrow opening, or throat,
of a slightly divergent nozzle. This forms
the upper part of this shell. In this manner
the entire cross section of the ejector will
be filled by high velocity gases, having nearly
the same velocity in any one cross section.
On the sides, there is, perhaps, about a 5% lag.
With this condition prevalent, it would be
practically impossible for the air or steam to
cause a back pressure by going back next to the
walls. In the old design this was undoubtedly
the main reason for the low vacuum obtained.

The secondary nozzle, #9, is screwed into
the part #8 and connects with the steam pass-
age #2. This part, #8, is a 'V' shaped piece,
with the vertex upward, and extending entirely
across the lower part of the upper combining
shell. The steam passage #2 is bored through
from the outside until it just overlaps the
middle, and at the outer end of the passage it

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is tapped for the steam line. A hole is drill-
ed and tapped from the bottom, in the middle of
part #8, and extends in to meet the steam pass-
age #2. This hole is tapped so that the nozzle
may screw in tight.

The steam from the secondary nozzle entrains
the vapor and air from the primary nozzle and
ejects it into the comparatively small throat of
the lower combining chamber #10. This is a
slightly divergent nozzle.

In this manner the secondary nozzle can
maintain the vacuum created and expel the mixture
against the atmospheric pressure, through #16.

In the analysis of the first design, the
authors feel confident that this new ejector will
give far better results than the first one did.

The authors regret not having had the time
to build this second machine, so that they might
have presented positive, instead of negative
results.
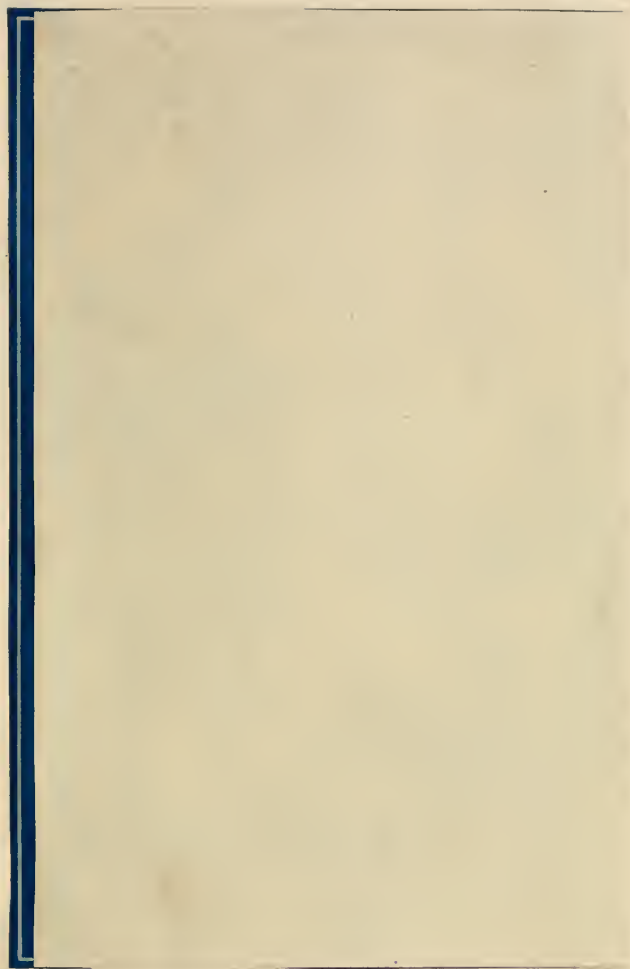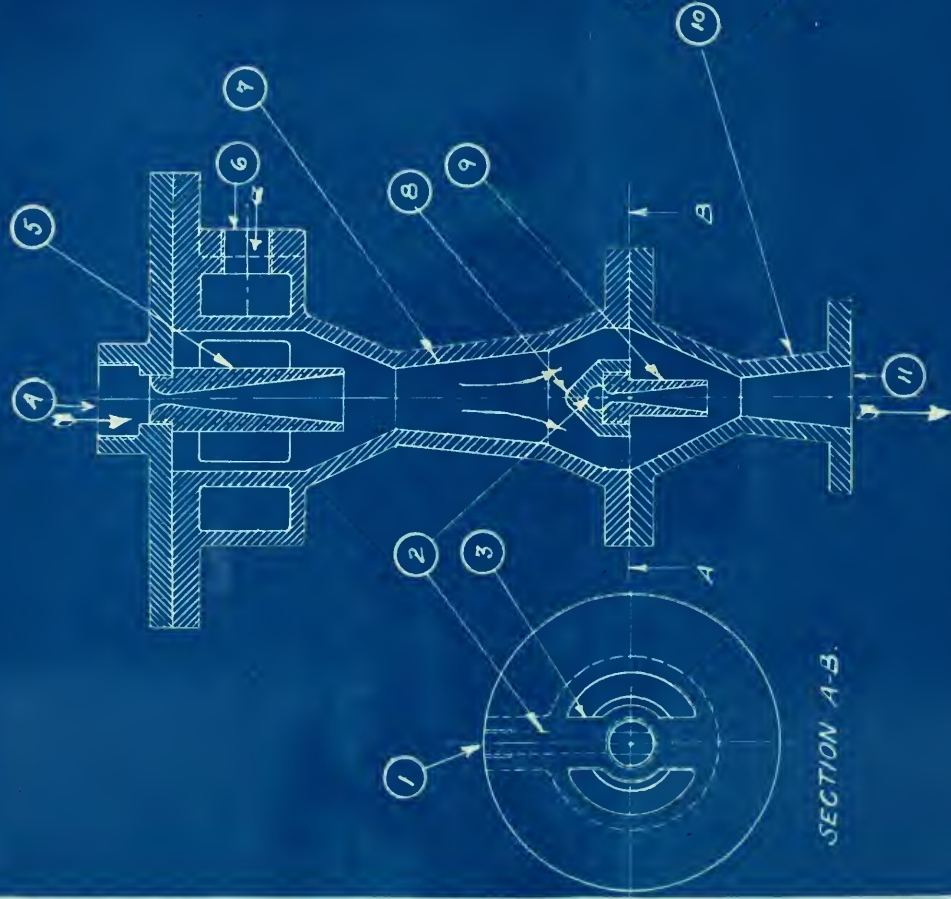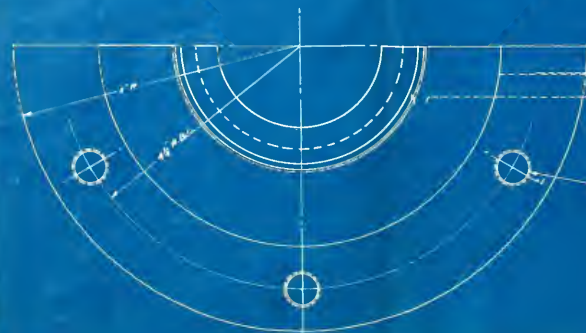
PROPOSED NEW DESIGN
OF
STEAM AIR-EJECTOR.

SECTION A-B.
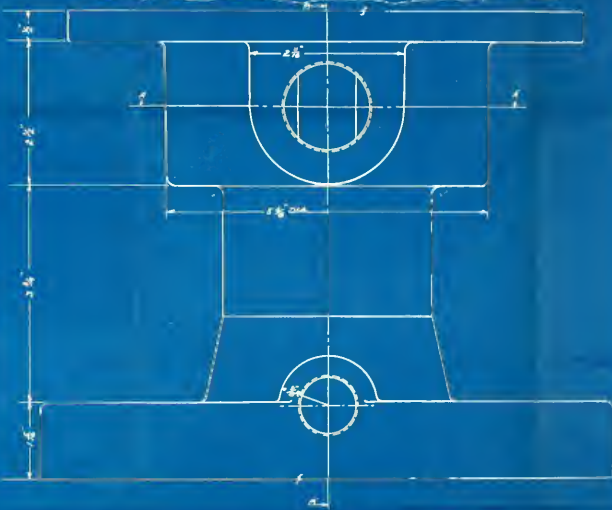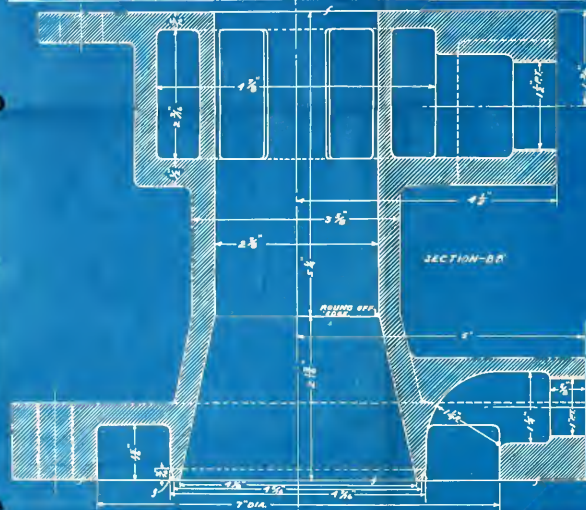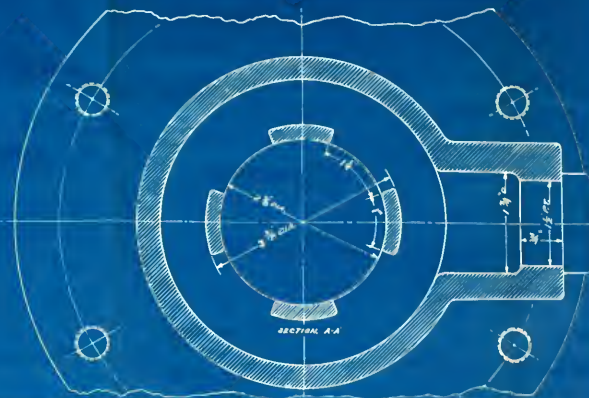
SECTION A·A

SECTION·BB

UPPER COMBINING SHELL

DRILL 6 - 3/8" HOLES

DRILL 6 - 3/8" HOLES

TOP PLATE
CAST IRON.

LOWER COMBINING TUBE
CAST IRON.

NOZZLE
BRASS.
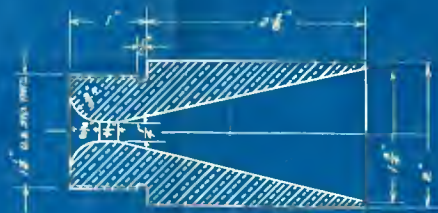
DRILL 4 - 3/8" HOLES.
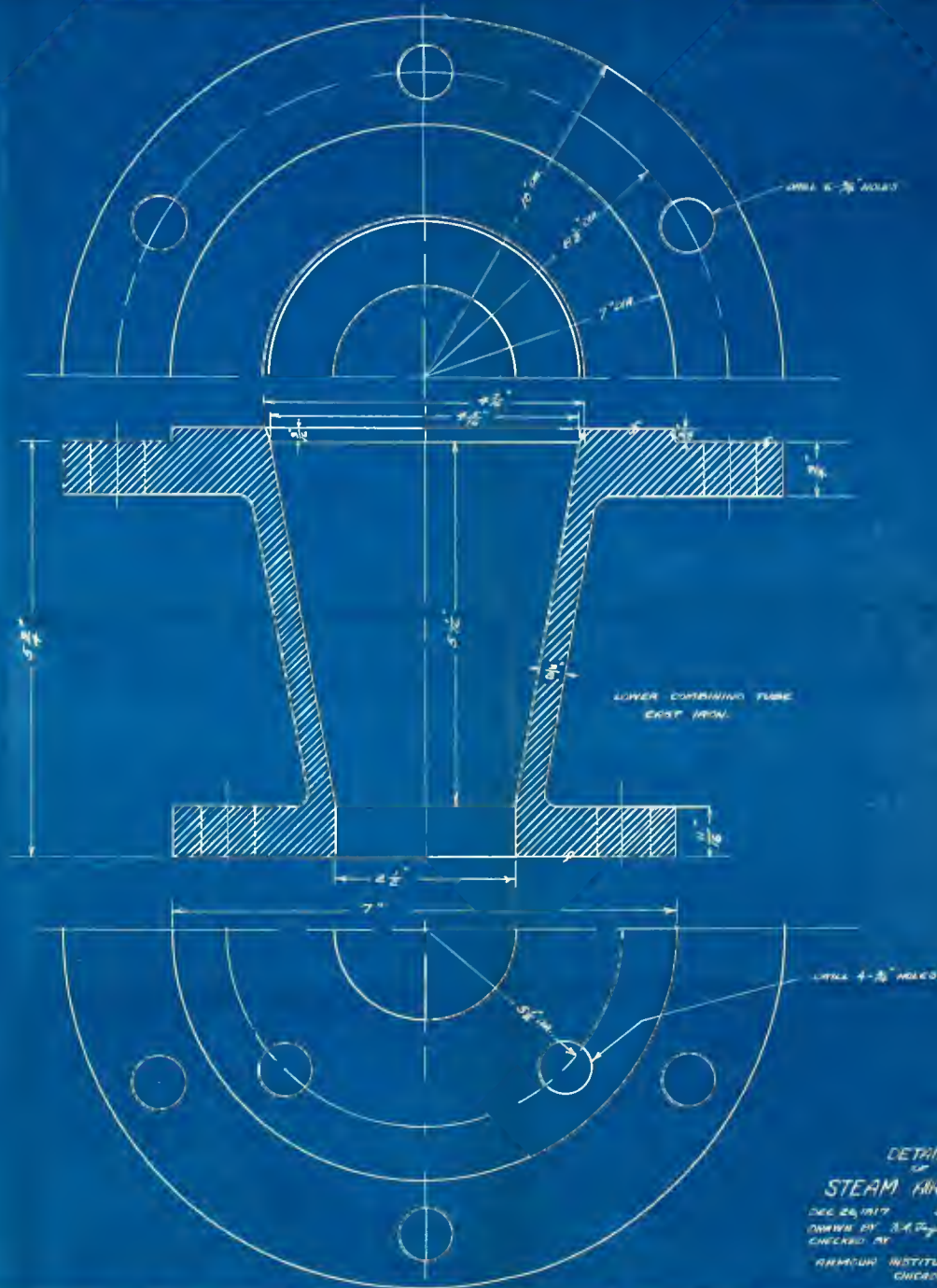
DETAILS
OF
STEAM AIR-EJECTOR
DEC 26, 1917   SCALE - FULL SIZE
DRAWN BY R.A. Taylor & R. J. Gee
CHECKED BY   THESIS 1918.
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

16-¾"

10" DIA.

9" DIA.

1ST STEAM JET.

2ND STEAM JET

AIR INTAKE
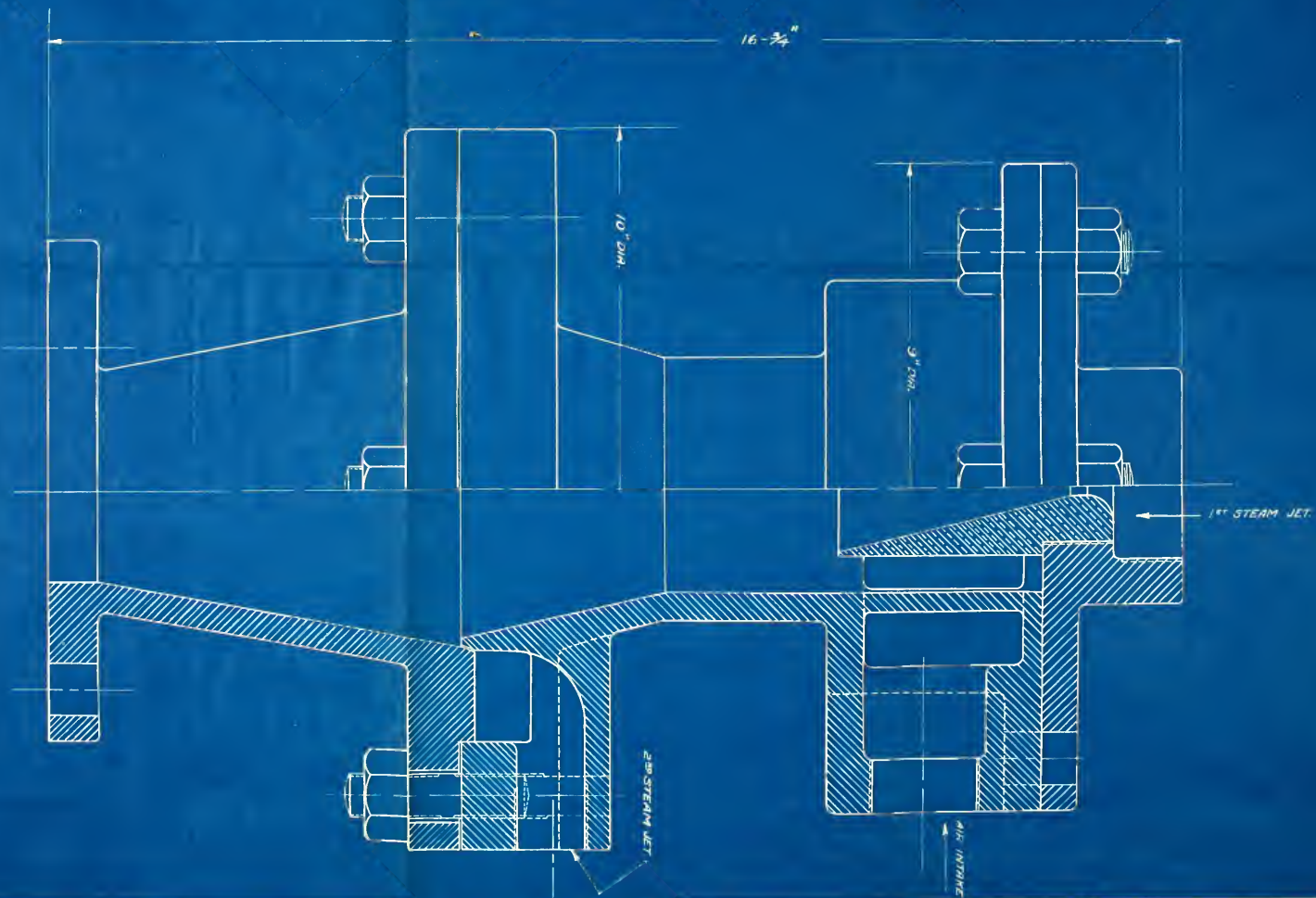
ASSEMBLY OF
STEAM AIR-EJECTOR
APRIL 1918   SCALE - FULL SIZE
DRAWN BY. R.Z. 6   THESIS 1918
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.